DETONATIVE CLEANING APPARATUS

BACKGROUND OF THE INVENTION

(1) Field of the Invention

[0001] The invention relates to industrial equipment. More particularly, the invention relates to the detonative cleaning of industrial equipment.

(2) Description of the Related Art

[0002] Surface fouling is a major problem in industrial equipment. Such equipment includes furnaces (coal, oil, waste, etc.), boilers, gasifiers, reactors, heat exchangers, and the like. Typically the equipment involves a vessel containing internal heat transfer surfaces that are subjected to fouling by accumulating particulate such as soot, ash, minerals and other products and byproducts of combustion, more integrated buildup such as slag and/or fouling, and the like. Such particulate build-up may progressively interfere with plant operation, reducing efficiency and throughput and potentially causing damage. Cleaning of the equipment is therefore highly desirable and is attended by a number of relevant considerations. Often direct access to the fouled surfaces is difficult. Additionally, to maintain revenue it is desirable to minimize industrial equipment downtime and related costs associated with cleaning. A variety of technologies have been proposed. By way of example, various technologies have been proposed in U.S. patents 5,494,004 and 6,438,191 and U.S. patent application publication 2002/0112638. Additional technology is disclosed in Huque, Z. Experimental Investigation of Slag Removal Using Pulse Detonation Wave Technique, DOE/HBCU/OMI Annual Symposium, Miami, FL., March 16-18, 1999. Particular blast wave techniques are described by Hanjalić and Smajević in their publications: Hanjalić, K. and Smajević, I., Further Experience Using Detonation Waves for Cleaning Boiler Heating Surfaces, International Journal of Energy Research Vol. 17, 583-595 (1993) and Hanjalić, K. and Smajević, I., Detonation-Wave Technique for On-load Deposit Removal from Surfaces Exposed to Fouling: Parts I and II, Journal of Engineering for Gas Turbines and Power, Transactions of the ASME, Vol. 1, 116 223-236, January 1994. Such systems are also discussed in Yugoslav patent publications P 1756/88 and P 1728/88. Such systems are often identified as "soot blowers" after an exemplary application for the technology.

[0003] Nevertheless, there remain opportunities for further improvement in the field.

SUMMARY OF THE INVENTION

[0004] One aspect of the invention involves an apparatus for cleaning a surface within a vessel. The apparatus is supported at least partially above a support surface. The apparatus had an elongate combustion conduit extending from an upstream end to a downstream end The downstream end is associated with an aperture in a wall of the vessel and positioned to direct a shock wave toward the surface. A guide member is on the support surface. A number of support assemblies support the combustion conduit at a number of locations along a length of the combustion conduit and engage the at least one guide member.

[0005] In various implementations, the at least one guide member may comprise at least one track. Each support may have at least one wheel engaging the at least one track. The at least one track may comprise first and second spaced apart rails. Each support assembly may comprise at least one pair of the at least one wheel being first and second spaced apart wheels. Each support assembly may comprise a trolley having first and second of the at least one pair of the at least one wheel. The combustion conduit may comprise a number of separable segments. Each of the segments may be supported atop a single associated one of the number of trolleys. A fuel and oxidizer source may be coupled to the combustion conduit to deliver a charge to the conduit. An ignitor may be positioned to ignite the charge to cause a deflagration to detonation transition for generating the shock wave. A resilient member may couple the combustion conduit to the wall. A number of such apparatus may be positioned at a given level of the vessel. The combustion conduits may be oriented parallel to each other.

[0006] The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is a view of an industrial furnace associated with several soot blowers positioned to clean a level of the furnace.

[0008] FIG. 2 is a side view of one of the blowers of FIG. 1.

[0009] FIG. 3 is a partially cut-away side view of an upstream end of the blower of FIG. 2.

[0010] FIG. 4 is a longitudinal sectional view of a main combustor segment of the soot blower of FIG. 2.

[0011] FIG. 5 is an end view of the segment of FIG. 4.

[0012] FIG. 6 is a view of a conduit segment support trolley of the system of FIG. 1.

[0013] FIG. 7 is a side view of an alternate combustion conduit.

[0014] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0015] FIG. 1 shows a furnace 20 having an exemplary three associated soot blowers 22. In the illustrated embodiment, the furnace vessel is formed as a right parallelepiped and the soot blowers are all associated with a single common wall 24 of the vessel and are positioned at like height along the wall. Other configurations are possible (e.g., a single soot blower, one or more soot blowers on each of multiple levels, and the like).

[0016] Each soot blower 22 includes an elongate combustion conduit 26 extending from an upstream distal end 28 away from the furnace wall 24 to a downstream proximal end 30 closely associated with the wall 24. Optionally, however, the end 30 may be well within the furnace. In operation of each soot blower, combustion of a fuel/oxidizer mixture within the conduit 26 is initiated proximate the upstream end (e.g., within an upstreammost 10% of a conduit length) to produce a detonation wave which is expelled from the downstream end as a shock wave along with associated combustion gases for cleaning surfaces within the interior volume of the furnace. Each soot blower may be associated with a fuel/oxidizer source 32. Such source or one or more components thereof may be shared amongst the various soot blowers. An exemplary source includes a liquified or compressed gaseous fuel cylinder 34 and an oxygen cylinder 36 in respective containment structures 38 and 40. In the exemplary embodiment, the oxidizer is a first oxidizer such as essentially pure oxygen. A second oxidizer may be in the form of shop air delivered from a central air source 42. In the exemplary embodiment, air is stored in an air accumulator 44. Fuel, expanded from that in the cylinder 34 is generally stored in a fuel accumulator 46. Each exemplary source 32 is coupled to the associated conduit 26 by appropriate plumbing below. Similarly, each soot blower includes a spark box 50 for initiating combustion of the fuel oxidizer mixture and which, along with the source 32, is controlled by a control and monitoring system (not shown). FIG. 1 further shows the wall 24 as including a number of ports for inspection and/or measurement. Exemplary ports include an optical monitoring port 54 and a temperature monitoring port 56 associated with each soot blower 22 for respectively receiving an infrared and/or visible light video camera and thermocouple probe for viewing the surfaces to be cleaned and monitoring internal temperatures. Other probes/monitoring/sampling may be utilized, including pressure monitoring, composition sampling, and the like.

[0017] FIG. 2 shows further details of an exemplary soot blower 22. The exemplary detonation conduit 26 is formed with a main body portion formed by a series of doubly

flanged conduit sections or segments 60 arrayed from upstream to downstream and a downstream nozzle conduit section or segment 62 having a downstream portion 64 extending through an aperture 66 in the wall and ending in the downstream end or outlet 30 exposed to the furnace interior 68. The term nozzle is used broadly and does not require the presence of any aerodynamic contraction, expansion, or combination thereof. Exemplary conduit segment material is metallic (e.g., stainless steel). The outlet 30 may be located further within the furnace if appropriate support and cooling are provided. FIG. 2 further shows furnace interior tube bundles 70, the exterior surfaces of which are subject to fouling. In the exemplary embodiment, each of the conduit segments 60 is supported on an associated trolley 72, the wheels of which engage a track system 74 along the facility floor 76. The exemplary track system includes a pair of parallel rails engaging concave peripheral surfaces of the trolley wheels. The exemplary segments 60 are of similar length L_1 and are bolted end-to-end by associated arrays of bolts in the bolt holes of their respective flanges. Similarly, the downstream flange of the downstreammost of the segments 60 is bolted to the upstream flange of the nozzle 62. In the exemplary embodiment, a reaction strap 80 (e.g., cotton or thermally/structurally robust synthetic) in series with one or more metal coil reaction springs 82 is coupled to this last mated flange pair and connects the combustion conduit to an environmental structure such as the furnace wall for resiliently absorbing reaction forces associated with discharging of the soot blower and ensuring correct placement of the combustion conduit for subsequent firings. Optionally, additional damping (not shown) may be provided. The reaction strap/spring combination may be formed as a single length or a loop. In the exemplary embodiment, this combined downstream section has an overall length L_2. Alternative resilient recoil absorbing means may include non-metal or non-coil springs or rubber or other elastomeric elements advantageously at least partially elastically deformed in tension, compression, and/or shear, pneumatic recoil absorbers, and the like.

[0018] Extending downstream from the upstream end 28 is a predetonator conduit section/segment 84 which also may be doubly flanged and has a length L_3. The predetonator conduit segment 84 has a characteristic internal cross-sectional area (transverse to an axis/centerline 500 of the conduit) which is smaller than a characteristic internal cross-sectional area (e.g., mean, median, mode, or the like) of the downstream portion (60, 62) of the combustion conduit. In an exemplary embodiment involving circular sectioned conduit segments, the predetonator cross-sectional area is a characterized by a diameter of between 8 cm and 12 cm whereas the downstream portion is characterized by a diameter of

between 20 cm and 40 cm. Accordingly, exemplary cross-sectional area ratios of the downstream portion to the predetonator segment are between 1:1 and 10:1, more narrowly, 2:1 and 10:1. An overall length L between ends 28 and 30 may be 1-15 m, more narrowly, 5-15 m. In the exemplary embodiment, a transition conduit segment 86 extends between the predetonator segment 84 and the upstreammost segment 60. The segment 86 has upstream and downstream flanges sized to mate with the respective flanges of the segments 84 and 60 has an interior surface which provides a smooth transition between the internal cross-sections thereof. The exemplary segment 86 has a length L_4. An exemplary half angle of divergence of the interior surface of segment 86 is ≤ 12°, more narrowly 5-10°.

[0019] A fuel/oxidizer charge may be introduced to the detonation conduit interior in a variety of ways. There may be one or more distinct fuel/oxidizer mixtures. Such mixture(s) may be premixed external to the detonation conduit, or may be mixed at or subsequent to introduction to the conduit. FIG. 3 shows the segments 84 and 86 configured for distinct introduction of two distinct fuel/oxidizer combinations: a predetonator combination; and a main combination. In the exemplary embodiment, in an upstream portion of the segment 84, a pair of predetonator fuel injection conduits 90 are coupled to ports 92 in the segment wall which define fuel injection ports. Similarly, a pair of predetonator oxidizer conduits 94 are coupled to oxidizer inlet ports 96. In the exemplary embodiment, these ports are in the upstream half of the length of the segment 84. In the exemplary embodiment, each of the fuel injection ports 92 is paired with an associated one of the oxidizer ports 96 at even axial position and at an angle (exemplary 90° shown, although other angles including 180° are possible) to provide opposed jet mixing of fuel and oxidizer. Discussed further below, a purge gas conduit 98 is similarly connected to a purge gas port 100 yet further upstream. An end plate 102 bolted to the upstream flange of the segment 84 seals the upstream end of the combustion conduit and passes through an igniter/initiator 106 (e.g., a spark plug) having an operative end 108 in the interior of the segment 84.

[0020] In the exemplary embodiment, the main fuel and oxidizer are introduced to the segment 86. In the illustrated embodiment, main fuel is carried by a number of main fuel conduits 112 and main oxidizer is carried by a number of main oxidizer conduits 110, each of which has terminal portions concentrically surrounding an associated one of the fuel conduits 112 so as to mix the main fuel and oxidizer at an associated inlet 114. In exemplary embodiments, the fuels are hydrocarbons. In particular exemplary embodiments, both fuels

are the same, drawn from a single fuel source but mixed with distinct oxidizers: essentially pure oxygen for the predetonator mixture; and air for the main mixture. Exemplary fuels useful in such a situation are propane, MAPP gas, or mixtures thereof. Other fuels are possible, including ethylene and liquid fuels (e.g., diesel, kerosene, and jet aviation fuels). The oxidizers can include mixtures such as air/oxygen mixtures of appropriate ratios to achieve desired main and/or predetonator charge chemistries. Further, monopropellant fuels having molecularly combined fuel and oxidizer components may be options.

[0021] In operation, at the beginning of a use cycle, the combustion conduit is initially empty except for the presence of air (or other purge gas). The predetonator fuel and oxidizer are then introduced through the associated ports filling the segment 84 and extending partially into the segment 86 (e.g., to near the midpoint) and advantageously just beyond the main fuel/oxidizer ports. The predetonator fuel and oxidizer flows are then shut off. An exemplary volume filled the predetonator fuel and oxidizer is 1-40%, more narrowly 1-20%, of the combustion conduit volume. The main fuel and oxidizer are then introduced, to substantially fill some fraction (e.g., 20-100%) of the remaining volume of the combustor conduit. The main fuel and oxidizer flows are then shut off. The prior introduction of predetonator fuel and oxidizer past the main fuel/oxidizer ports largely eliminates the risk of the formation of an air or other non-combustible slug between the predetonator and main charges. Such a slug could prevent migration of the combustion front between the two charges.

[0022] With the charges introduced, the spark box is triggered to provide a spark discharge of the initiator igniting the predetonator charge. The predetonator charge being selected for very fast combustion chemistry, the initial deflagration quickly transitions to a detonation within the segment 84 and producing a detonation wave. Once such a detonation wave occurs, it is effective to pass through the main charge which might, otherwise, have sufficiently slow chemistry to not detonate within the conduit of its own accord. The wave passes longitudinally downstream and emerges from the downstream end 30 as a shock wave within the furnace interior, impinging upon the surfaces to be cleaned and thermally and mechanically shocking to typically at least loosen the contamination. The wave will be followed by the expulsion of pressurized combustion products from the detonation conduit, the expelled products emerging as a jet from the downstream end 30 and further completing the cleaning process (e.g., removing the loosened material). After or overlapping such venting of combustion products, a purge gas (e.g., air from the same source providing the main

oxidizer and/or nitrogen) is introduced through the purge port 100 to drive the final combustion products out and leave the detonation conduit filled with purge gas ready to repeat the cycle (either immediately or at a subsequent regular interval or at a subsequent irregular interval (which may be manually or automatically determined by the control and monitoring system)). Optionally, a baseline flow of the purge gas may be maintained between charge/discharge cycles so as to prevent gas and particulate from the furnace interior from infiltrating upstream and to assist in cooling of the detonation conduit.

[0023] In various implementations, internal surface enhancements may substantially increase internal surface area beyond that provided by the nominally cylindrical and frustoconical segment interior surfaces. The enhancement may be effective to assist in the deflagration-to-detonation transition or in the maintenance of the detonation wave. FIG. 4 shows internal surface enhancements applied to the interior of one of the main segments 60. The exemplary enhancement is nominally a Chin spiral, although other enhancements such as Shchelkin spirals and Smirnov cavities may be utilized. The spiral is formed by a helical member 120. The exemplary member 120 is formed as a circular-sectioned metallic element (e.g., stainless steel wire) of approximately 8-20mm in sectional diameter. Other sections may alternatively be used. The exemplary member 120 is held spaced-apart from the segment interior surface by a plurality of longitudinal elements 122. The exemplary longitudinal elements are rods of similar section and material to the member 120 and welded thereto and to the interior surface of the associated segment 60. Such enhancements may also be utilized to provide predetonation in lieu of or in addition to the foregoing techniques involving different charges and different combustor cross-sections.

[0024] The apparatus may be used in a wide variety of applications. By way of example, just within a typical coal-fired furnace, the apparatus may be applied to: the pendants or secondary superheaters, the convective pass (primary superheaters and the economizer bundles); air preheaters; selective catalyst removers (SCR) scrubbers; the baghouse or electrostatic precipitator; economizer hoppers; ash or other heat/accumulations whether on heat transfer surfaces or elsewhere, and the like. Similar possibilities exist within other applications including oil-fired furnaces, black liquor recovery boilers, biomass boilers, waste reclamation burners (trash burners), and the like.

[0025] FIG. 6 shows further details of the exemplary trolley 72 and track system 74. The exemplary track system comprises a pair of parallel vertex-up right angle channel elements 140 (e.g., of steel) secured such as by welding to mounting plates 142. The mounting plates are, in turn, secured to the floor 76 such as via bolts (not shown) in bolt holes 144. The exemplary trolley includes a structural frame 150 having a pair of left and right longitudinal members 152 and fore and aft crossmembers 154. At the left and right sides of each crossmember, a wheel 156 is mounted on a depending bracket 158. The wheel periphery has a concavity (e.g., a right-angle V-groove 160) receiving the vertex of the right angle channel elements 140. The exemplary trolley has means for supporting the associated conduit segment and means for securing the segment in place. The exemplary support means include a pair of fore and aft tube/pipe clamps 170 each positioned and supported by nuts 172 on associated left and right threaded shafts 174 secured at their lower ends to the frame. The clamps 170 have a concave surface 176 complementary to the exterior body surface of the associated conduit segment to support the segment from below. The securing means comprises similar top brackets 180 also mounted to the shafts 174 and held downward in place in compressive engagement with the segment via nuts 182.

[0026] A number of options are available for using the trolleys. The individual segments may be preassembled to their associated trolleys and rolled into place along the track system, whereupon the segments may be secured to each other via their end flanges. Disassembly may be by a reverse of this process. The trolleys may also allow the combustion conduit to be moved as a unit (e.g., if it is desired that the downstream portion of the conduit not be inserted into the furnace all the time). Additionally, as noted above, the trolleys may accommodate movement as a unit associated with longitudinal thermal expansion and/or with recoil during discharge cycles while maintaining conduit segment alignment.

[0027] FIG. 7 shows an alternate system 200 wherein the combustion conduit 202 is suspended from brackets 204 (e.g., as part of a free-standing support structure or secured to a ceiling or roof 206 of the facility). Such a system may be particularly useful where the conduit is positioned high above a facility floor. The exemplary system 200 navigates the conduit 202 around environmental obstacles external to the furnace. Exemplary obstacles include upper and lower tube bundles 210 and 212 between which the conduit passes. In the exemplary embodiment, the conduit is circuitous to permit positioning of its outlet 214 in a position on the furnace wall aligned with one of the two bundles. In such a situation, a straight conduit

would be interfered with by the bundles. Accordingly, the conduit is provided with one or more curved sections 216 to accommodate the bundles.

[0028] From upstream to downstream, the exemplary support system includes an upstream and an intermediate spring hanger 220 and 222 coupled to associated conduit segments by turnbuckle systems 224 and 226. Exemplary spring hangers are available from LISEGA, Inc., Newport, Tennessee. In the exemplary embodiment, the spring hanger 222 may have substantially higher capacity due to a higher static load at that location. The particular combination of hanger sizings may be influenced by the relative locations of the hangers along the conduit in view of mass parameters of the conduit (e.g., center of gravity, mass distribution, and the like), strength parameters of the conduit (e.g., various modulus), and the location of any additional support. The exemplary spring hangers serve as essentially constant-load hangers, with supportive tensile force essentially constant over an operating range. One function of the vertical compliance afforded by the hangers is to accommodate thermally-associated changes in the vertical position of the outlet 214 relative to the ceiling surface 206 or other combustion conduit support structure. For example, thermal expansion of the furnace wall may cause a change in outlet vertical position between hot and cold (e.g., running and off) furnace conditions. In the embodiment of FIG. 2, such expansion is addressed by non rigid vertical coupling of the conduit and wall with sufficient vertical play for the conduit within the oversized wall aperture. With rigid mounting, however, if furnace heating raises the conduit outlet height, in the absence of the constant force hangers, a greater fraction of the conduit mass would be carried by the furnace wall and a lesser fraction by the upstream supports. This would be associated with shear/bending forces/moments and associated deformations. The spring hangers, however, will tend to contract, raising the segment(s) to which they are attached to so that the mass supported by the furnace wall does not substantially increase and thus to at least partially, and advantageously in major part, relieve/prevent stresses that otherwise would be associated with the outlet elevation increase. the hangers may, therefore maintain an essentially constant orientation of the conduit (e.g., maintaining its upstream major portion in an essentially horizontal orientation).

[0029] In the exemplary embodiment, a support structure 240 external to the combustion conduit further reinforces the associated assembled segments. Such reinforcement advantageously handles structural stresses associated with shock reflections occurring within the curved segments. In the illustrated embodiment, the structure further rigidly ties

downstream portions of the conduit to the furnace wall. In the exemplary embodiment, the turnbuckle 226 is connected via its lower threaded rod to a fixture 242 secured to the upstream end of the support structure and having snubbers 244 to accommodate and dampen side-to-side motion of the conduit which may arise from the combustion process. In the exemplary embodiment, the rigid connection of the support structure to the furnace wall absorbs the recoil forces, essentially preventing recoil. To the extent that longitudinal thermal expansion of the conduit remains an issue, such expansion may be taken up by allowing the hangers to pivot (e.g., relative to connection locations 246 to the brackets 204 above and the connection point 248 with the associated conduit engagement fixture below. Alternative embodiments may remove the rigid coupling of the conduit to the wall and permit a resilient or damped coupling.

[0030] One or more embodiments of the present invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. For example, the invention may be adapted for use with a variety of industrial equipment and with variety of soot blower technologies. Aspects of the existing equipment and technologies may influence aspects of any particular implementation. Accordingly, other embodiments are within the scope of the following claims.